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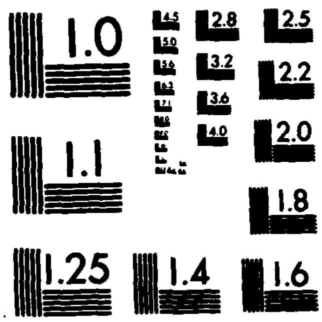

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ALKALI-SILICA REACTION IN CONCRETE IN A NORTH DAKOTA HIGHWAY

by

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Final Report

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Prepared for North Dakota State Highway Department
Bismarck, N. D. 58502

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The North Dakota State Highway Department found cracking in concrete on Interstate Highway 94 east of Dickinson in about 1979 when the concrete was about 15 years old. While the cracking was primarily in the eastbound lanes where high-alkali portland cement had been used, it had the appearance of "D" cracking. The fine aggregate was local natural sand with a good service record, while the coarse aggregate was a mixed gravel from eastern Montana with no known service record. The question therefore was:

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20. ABSTRACT (Continued)

"Is the cracking due to alkali-silica reaction, to freezing and thawing, or to both, or to some other factor or factors?"

Petrographic examination of concrete cores from the cracked pavement and dilation testing of some of these for resistance to freezing and thawing showed the presence of significant amounts of products of alkali-silica reaction and satisfactory frost resistance. It was concluded that the cracking was due to alkali-silica reaction.

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Preface

The work described in this report was done for the North Dakota State Highway Department at the request of Mr. David K. O. Leer of that department. The work was done in the Concrete Technology Division (CTD) of the Structures Laboratory (SL), U. S. Army Engineer Waterways Experiment Station (WES). It was done under the direction of Mr. John M. Scanlon, Chief, CTD, and Mr. Bryant Mather, Chief, SL. Mr. Alan D. Buck, CTD, was project leader and prepared this report.

The Concrete Technology Information Analysis Center (CTIAC) provided funds to publish this report; it is CTIAC Report No. 68. The permission of Mr. Leer to publish the report is appreciated.

COL Tilford C. Creel, CE, was Commander and Director of WES when this report was prepared for publication. Mr. F. R. Brown was Technical Director.

Contents

Conversion Factors, Non-SI to SI (Metric)
Units of Measurement

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
inches	25.4	millimetres
Fahrenheit degrees	5/9	Celsius degrees or kelvins*
feet	0.3048	metres
miles (U. S. statute)	1.609347	kilometres

* To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use the following formula: C = (5/9)(F - 32). To obtain kelvin (K) readings, use: K = (5/9)(F - 32) + 273.15.

ALKALI-SILICA REACTION IN CONCRETE IN A NORTH DAKOTA HIGHWAY

Background

1. On 8 January 1981, Mr. Alan D. Buck of the Waterways Experiment Station (WES) met with representatives of the North Dakota State Highway Department, and the party inspected a portion of Interstate Highway 94 just east of Dickinson, N. D. The intent was to observe the type and frequency of cracking that had developed over the last 2 years in the south (eastbound) lanes of this 17-year-old pavement over an area approximately 30 miles* long.

2. The concrete pavement is 9 in. thick and has expansion joints every 61.5 ft in the area that was inspected. Observations showed that, while the lanes in both directions showed transverse relief cracks spaced about 20 ft apart, the eastbound lanes also showed a series of closely spaced cracks extending out about 1 ft on both sides of joints. These tended to parallel the joints and then to round the corners at pavement edges and extend about 3 ft before dying out. There were also some areas of longitudinal cracking and map cracking. The highway department had photographs illustrating this cracking in all stages of development. The cracking near joints resembled what is generally referred to as "D" cracking. A high-alkali portland cement had been used in the heavily cracked areas, whereas one or more low-alkali portland cements had been used in the relatively uncracked areas. Thus, a natural question was whether alkali-silica reaction had taken place. Since the coarse aggregate had not been specifically evaluated for frost resistance, there was also a question of whether the cracking was due to frost damage. Even though the concrete was air entrained, this would not protect the concrete if the coarse aggregate was not durable. The fine aggregate was a local natural sand that had a satisfactory service record.

3. On 9 January 1981, it was agreed that the Structures Laboratory (SL), WES, would undertake a program to answer the following questions:

   a. Had alkali-silica reaction taken place in the heavily cracked concrete?

   b. Was this concrete frost resistant?

It was also requested that comments be provided about the possible use of a membrane moisture barrier between the present concrete surface and an overlay if such repair was made.

Samples

4. Mr. Buck inspected some concrete fragments from a large piece sawed from the heavily cracked area and brought some of these back to the laboratory at WES. This sample was identified as CR 272 from Mile 79.9 by the highway department.

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* A table of factors for converting non-SI units of measurement to SI (metric) units is presented on page 3.

5. One box containing 10 concrete cores and a bag of concrete fragments were received at WES on 23 January 1981. All of the cores were 2-1/4-in. diameter (~0.18 ft) and about 9 in. long (0.75 ft). Serial numbers were assigned; these and other information are shown below:

SL Serial No.	Description	Mile	Length, ft
CL-37			
CON-1	Core 1. No visible cracking.	79.6	0.75
CON-2	Core 2. Horizontal crack at 0.30 ft; gel is evident.	80.0	0.77
CON-3	Core 3. No visible cracking.	81.1	0.78
CON-4	Core 4. No visible cracking.	81.4	0.77
CON-5	Core 5. No visible cracking; some gel on surface.	82.9	0.75

The above five cores were from the heavily cracked eastbound lanes, but none of them contained a surface crack.

CON-6	Core 6. No visible cracking.	84.0	0.77
CON-7	Core 7. No visible cracking; piece of ~1/4-in. steel was present in core.	83.0	0.75
CON-8	Core 8. No visible cracking.	82.4	0.75
CON-9	Core 9. No visible cracking; piece of steel as in Core 7.	81.0	0.77
CON-10	Core 10. No visible cracking.	78.0	0.77

Cores 6 through 10 were from the relatively uncracked westbound lanes.

6. The bag of concrete fragments was more of the CR 272 specimen that Mr. Buck had inspected in Bismarck.

Test Procedure

7. The 10 cores were measured and inspected. When Core 2 broke along an existing horizontal crack during sawing, a photograph was taken of this broken surface.

8. Cores 1, 3, 4, 5, 6, 7, 9, and 10 were selected as being representative of the cracked and uncracked highway. The broken ends of all were removed by sawing to obtain cores about 6 in. long. Holes were drilled in the ends of each core and metal inserts were fastened in place with epoxy resin.

9. Cores 1, 5, 7, and 9 were to be used for length-change testing. Their lengths were measured while they were dry; they were then placed in tap water and measured daily for 3 days. When the lengths were not changing appreciably after 3 days in water, they were taken as reference lengths and testing was started. This consisted of storage at 100° F (37.8° C) in 100 percent relative humidity and weekly length measurements at 73° F (22.8° C) after overnight cooling. Length changes were calculated and recorded.

10. Cores 3, 4, 6, and 10 were to be tested for dilation. They were soaked in limewater for 10 days. This was intended to get them as wet or wetter than the highway concrete they represented would actually be in the field. A single cycle freezing test was made using Cores 3, 4, 10, and a control that had been in limewater for about 5 years. After 53 days of storage in water-saturated kerosine, Core 6 and the control were given the same test. The test was made essentially as described in ASTM C 671-77.[1] Interpretation of the data was as recommended by Buck.[2]

11. Cores 2 and 8, the unused portions of the other eight cores, and the bag of concrete fragments were used for the petrographic examination. Cores 2 and 8 were cut longitudinally and a sawed surface of each was ground to remove saw marks. These smoothed surfaces were examined with a stereomicroscope. White material from two voids in Core 2 and from a void in one of the concrete fragments (CR 272) was prepared as immersion mounts in an oil with a refractive index of 1.544; these immersion mounts were examined with a polarizing microscope. The broken surfaces of some of the concrete fragments (CR 272) were examined with a stereomicroscope; the unused part of Core 8 was broken into several pieces and these freshly broken surfaces were also examined this way.

12. A thin section from Core 2 and one from Core 8 were made. They were impregnated with a fluorescent dye. They were examined with a polarizing microscope using plane polarized light and also with crossed polarizers. In addition, they were also examined using a suitable light source to excite the dye and filters to screen out unwanted wavelengths.

Results

13. Cursory inspection of concrete fragments from specimen CR 272 in Bismarck had shown that evidence of alkali-silica reaction was present. The laboratory work was done to determine if the reaction was common in the cracked concrete of the eastbound lanes, whether the reaction was completed, and if it was solely responsible for this cracking or if frost damage was also involved.

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1 "Standard Test Method for Critical Dilation of Concrete Specimens Subjected to Freezing," 1980 Annual Book of ASTM Standards, Part 14, American Society for Testing and Materials, Philadelphia, Pa.

2 Buck, A. D., "Investigation of Frost Resistance of Mortar and Concrete," p 17, U. S. Army Engineer Waterways Experiment Station, CE, Technical Report No. C-76-4, Oct 1976, Vicksburg, Miss.

14. This work has shown that evidence of alkali-silica reaction was common in the cores representing cracked concrete made with high-alkali cement (Cores 1 through 5) and in the fragments of sample CR 272. This was seen as cracking, rims on reacted aggregate, and by the presence of white alkali-silica gel; the rims and gel are well shown by Photograph 1. The fact that reaction rims were present on coarse aggregate particles, that this was a mixed gravel with different kinds of rock particles, including igneous rock particles, and proximity of gel to coarse aggregate particles all indicate the coarse aggregate was reactive. The type or types of reactive constituents were not identified. Normally, one would hesitate to say these were reaction rims instead of weathering rims since the material was natural gravel but the preponderance of other evidence suggests they are reaction rims. There was no specific indication of reaction by the fine aggregate. Definite evidence of alkali-silica reaction was not found in Cores 6 through 10 representing concrete made with low-alkali cement.

15. Length-change data for Cores 1, 5, 7, and 9 are shown in Table 1. The intent was to determine whether the expansive potential of the alkali-silica reaction was completed for Cores 1 and 5 and whether there was such potential for Cores 7 and 9. The readings were made with a comparator reading to thousandths instead of to tens of thousandths because the specimens differed too much in overall length. The values are not considered to be as reliable as desired for that reason. These data could be interpreted to mean that all four of the cores had significant expansive potential as typified by expansions of 0.07 to 0.12 percent at 70 days. The concrete represented by Cores 7 and 9 has not shown significant cracking in the field during about 17 years with opportunity for this to occur. The five cores with low-alkali cement (Cores 6 through 10) did not show any definite evidence of alkali-silica reaction in the laboratory. Examination of these four cores after 91 days of testing showed that Cores 1 and 5 formed some deposits of white gel on their surfaces while Cores 7 and 9 did not form any gel deposits. Therefore, it is concluded that the readings tend to be too high due to the comparator used and to some expansion due to pickup of more moisture during storage, possibly combined with some reaction expansion. On this basis the data are interpreted as indicating little or no damaging expansive potential for either set of cores.

16. Inspection of the 10 cores did not show the presence of the type of cracking usually associated with freezing and thawing damage. Dilation data for Cores 3, 4, 6, and 10 are shown in Table 2 for one cycle of freezing to temperatures down to about 8 to 14° F. Division of the total dilation by core lengths of about 6 in. gave a range in dilation of 15 to 25 millionths (μin./in.). According to the criteria proposed by Buck,[2] the concrete represented by these cores is frost resistant.

Discussion

17. As mentioned earlier, some of the cracking seen in the eastbound lanes of I-94 resembled "D" cracking, and "D" cracking is generally due to frost damage. However, if the cracking was due to frost damage, it would have been expected to be also present in the westbound lanes.

This comment is based on the assumption that both concretes were of similar quality and differed significantly only in the cements used. Since such cracking was restricted to the eastbound lanes made with high-alkali cement, the field indication was that the cracking was not due to frost damage. The dilation data obtained in the laboratory prove that the cracking was not due to frost damage. There is significant cracking that is restricted to concrete containing high-alkali cement; cracking was seen to traverse both aggregates and paste in thin sections; there is abundant evidence of alkali-silica reaction associated with cracking. These facts plus the fact that frost damage was not a significant factor are adequate proof that the cracking that has caused concern was due to the effects of alkali-silica reaction. The cracking concentrated at the joints because they afforded more opportunity for moisture to penetrate the concrete once the joint sealer aged or came out. It is likely that there has been some effect of frost action by the wedging effect of moisture frozen in cracks caused by the alkali-silica reaction.

18. The placing of nearby lanes of concrete using the same reactive coarse aggregate and differing only in the use of high- or low-alkali cement was in effect a field test of the efficiency of low-alkali cement in preventing deleterious alkali-silica reaction. Therefore, it is recommended that the future performance of the pavement containing low-alkali cement should be monitored and reported as useful information to those concerned with alkali-silica reaction and control measures for it. This information will also be of direct use to the North Dakota State Highway Department as guidance in the selection and use of materials.

19. If a waterproof membrane were to be used between the surface of the cracked concrete and an overlay, the intent would be to keep the cracked concrete dryer than it would be without the presence of such a membrane. There would seem to be a possibility that such a membrane might trap moisture by preventing evaporation and thus make the cracked concrete wetter rather than dryer. Since it seems impossible to predict which effect would dominate if a membrane were used, it is recommended that this be determined by laboratory experimentation or by small-scale field testing or by a combination of both.

<u>Summary</u>

20. After field inspection of cracked and noncracked concrete and laboratory examination and testing of representative cores from this concrete, the following conclusions were made:

a. The coarse aggregate was reactive in the alkali-silica reaction.

b. The presence of this reactive aggregate in those sections of road that also contained high-alkali cement resulted in alkali-silica reaction in water accessible areas (i.e., joints) that was responsible for the deleterious cracking that has become so pronounced in the last 2 years.

c. Laboratory length-change data suggest expansion due to this reaction has been largely completed in the cracked areas. However, it is probable that the uncracked concrete made with high-alkali cement still has this expansive potential if conditions for reaction improved; in this case, this would mean the presence of more water.

d. The use of low-alkali cement with reactive aggregate in those sections of road that have not shown this deleterious cracking has thus far provided adequate control against this reaction, especially near joints.

e. Single-cycle dilation tests showed that all of the concrete represented by the cores is frost resistant.

Table 1

Length-Change of Four Concrete Cores from North Dakota Highway I-94*

Specimens	Length-Change, %, at Ages Shown Below, days										
	7	14	21	28	35	42	49	56	63	70	91
Core No. 1**	0.05	0.07	0.05	0.02	0.03	0.05	0.05	0.05	0.07	0.07	0.03
Core No. 5**	0.07	0.12	0.12	0.10	0.12	0.14	0.12	0.14	0.14	0.12	0.08
Average	0.06	0.10	0.08	0.06	0.08	0.10	0.08	0.10	0.10	0.10	0.06
Core No. 7†	0.09	0.11	0.09	0.08	0.09	0.11	0.11	0.11	0.11	0.09	0.08
Core No. 9†	0.10	0.12	0.10	0.08	0.10	0.12	0.10	0.10	0.08	0.08	0.06
Average	0.10	0.12	0.10	0.08	0.10	0.12	0.10	0.10	0.10	0.08	0.07

* Stored at 37.8° C (100° F) and 100 percent R.H.
** Made with high-alkali portland cement.
† Made with low-alkali portland cement.

Table 2

Dilation of Four Concrete Cores* from Highway I-94 During One Cycle of Freezing**

Specimens†	Dilation During One Cycle of Freezing: Total, μin.	Millionths (μin./in.)
Core No. 3	~100	~15
Core No. 4	~150	~25
Core No. 6	~150	~25
Core No. 10	~150	~25

* Each core was soaked 10 days in limewater prior to the test; core No. 6 was kept in water-saturated kerosine for 53 days between the water soaking and the test.
** Essentially done as a single cycle version of ASTM C 671-77 and ASTM Designation C 682-75.
† Cores 3 and 4 were from the south (eastbound) lanes; Cores 6 and 10 were from the north (westbound) lanes.

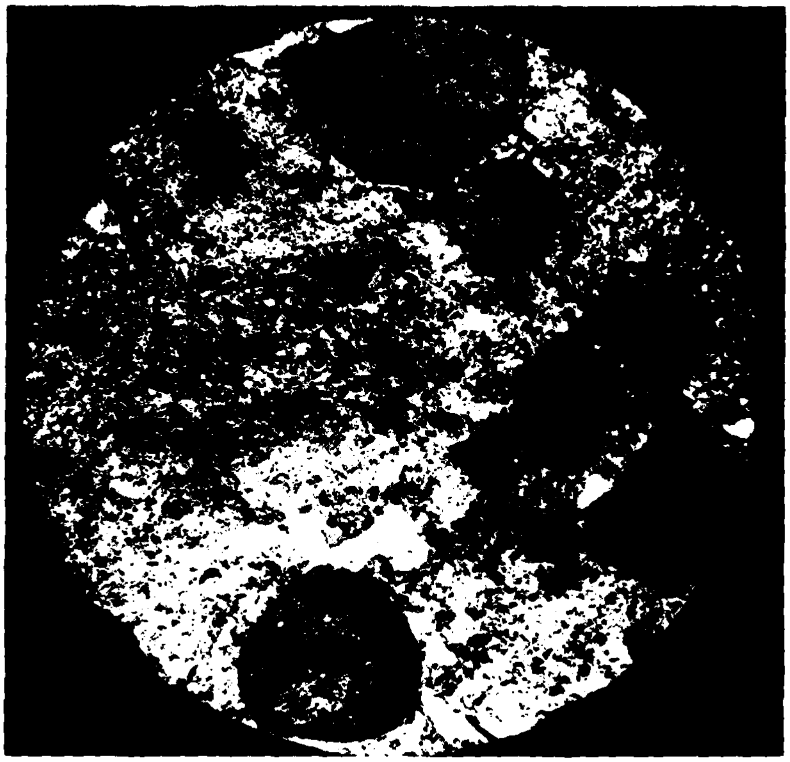

Photo 1. Broken surface of core No. 2, X1.8. This core is from the south (eastbound) lanes of Interstate Highway 94. Several aggregate particles with reaction rims and several areas of white alkali-silica reaction gel are evident